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# Tagging and Tracking Technologies for Freshwater and Marine Fishes

**PURPOSE:** This technical note presents an overview of tagging options, telemetry hardware (receiver, hydrophones, etc.,), detection ranges, fish capture and handling procedures, and tag attachment methods for consideration when designing and executing studies to tag and track aquatic and marine fish species. The existing technology is summarized with regard to capabilities, costs, availability, and advantages and disadvantages of each type.

**INTRODUCTION:** Acoustic tags have been used for monitoring fish movement for more than three decades. The National Marine Fisheries Service made one of the first attempts at using this technology in 1955 by attaching 132-kHz tags to adult Chinook and Coho salmon (Trefethen 1956). Since this initial study, "telemetry" has been used both in the United States and abroad to track movements of many fish species, mostly notably salmonids (Lacroix and McCurdy 1996, Steig 1999). In addition, telemetry has been used extensively in tracking marine mammals such as manatees (Reid 2001), reptiles (e.g., sea turtles (Keinath et al. 1989)) and numerous terrestrial wildlife species (Mech and Barber 2002). In recent years, electronic tag types and systems for tracking fish in both marine and freshwater environments have proliferated. Reduction in tag size and weight, along with increases in tag "life" and signal strength, has expanded telemetry applications for better management of threatened and endangered species. Although this technology has broad applications, this technical note will focus primarily on aquatic and marine fish species.

**HARDWARE:** Significant advances in telemetry technology have been made in recent years with the integration of multiple types of transmitters and receivers. All systems operate on the premise of transmitting information from fish to researchers in the form of sound energy transmission, either in radio (20 to 300 MHz), ultrasonic (20-300 kHz), or satellite (UHF 401.650 MHz) frequencies. The latest technological advance is the advent of combined sonic and radio transmitters. Ultrasonic and radio telemetry methods are reviewed by Winter (1983). Basic considerations of components necessary for telemetry studies are discussed below.

**TELEMETRY AND TAGGING OPTIONS:** Much of the advancement in telemetry technology has been in the area of tag development; however, tag selection is still greatly dependent on the type of data that the user wants to obtain. Several factors must be considered when choosing transmitters, including size of the tag relative to body size of the target species and life history stage, battery longevity and detection range. These factors are directly related to battery size, in that larger batteries increase the operational life expectancy of the tag along with signal strength, but require increased overall dimensions and weight. These factors are typically trade-offs for all telemetry studies in that a requirement to monitor a specific species for a prolonged period of time may require a tag size and weight that are unsuitable for that species to handle without affecting behavior or survivability. The generally accepted practice is to limit the

tag size to less than 2 percent of total body weight. Typically, researchers use the largest tag appropriate for the species under study. From this constraint, the range of detection and the tag operational life are determined.

Electronic tags can be divided into three basic categories to include transponding, data storage or archival, and transmitting. Although the focus of this technical note is tagging and tracking of aquatic and marine fishes, each category will be discussed briefly along with a prominent tagging option.

**Transponding Tags.** The Passive Integrated Transponding (PIT) tag is an inert, small glass-encapsulated electromagnetic coil and microchip that is inserted into the body cavity or muscle mass of a fish using a veterinary syringe. Tags are activated and the emitted signal read by a device held approximately 10-15 cm from the tagged animal. The signal is a unique alpha-numeric code (signal strength 40-50 kHz) for each tagged fish. Automatic readers are also available with either a tunnel detector (up to 30-cm diameter) or a strip detector, which can be placed on the streambed (up to 20-cm water depth). Pit tags generally range from 11 to 28 mm in length and 2.1 to 3.5 mm in diameter. Two systems are currently marketed (Trovan and Destron); however, they are not compatible, i.e. their respective reader devices will not detect the other's signal. Web site addresses are provided for each manufacturer at the end of this technical note.

Two example studies using PIT tags include measuring the migration of wild Snake River Chinook salmon smolts (Achord et al. 1998) and designing a tag system for monitoring American shad and blueback herring in fishways (Castro-Santos et al. 1996). The tags were implanted in the juvenile fish at the beginning of their migration. Each tag is unique and identifies one particular fish. Detectors located at dams can read the tags on the out-migration and when the fish return as adults to spawn.

Advantages of PIT tag usage include detection in both aquatic and marine environments, and the availability of billions of unique codes (Prentice et al. 1990). PIT tags are also economical, costing approximately $6 per tag, as compared to transmitting tags that cost hundreds of dollars each. A PIT tag requires no power source and the tag remains inactive inside the fish for its lifetime, until activated at a PIT-tag monitoring station or by a hand-held reader. The limiting usage factor for many studies is a very short detection range of 20 cm.

**Data Storage Tags (DST) or Archival Tags.** Data storage tags, also known as archival tags, may function simply as data loggers that measure temperature and water depth, for example, or as sophisticated programmable devices capable of recording direct estimates of the geographical position of a fish at regular intervals over periods of months to years (Thorsteinsson 2002). DSTs are also capable of recording temperature, depth, salinity, pressure, light and chemical and physiological indicators at set intervals. They have been used in open-water environments with free ranging fish such as tuna, Pacific and Atlantic salmon, sea trout and cod, among others. Advantages include the ability to collect data for up to five years and to store this information within the tag for up to twenty years. This allows a vast amount of data to be collected by a solitary tagging event. There are two primary disadvantages with DST tags. These include the high cost associated with the tags as well as the necessity to recapture the animal to

retrieve the tag to download the stored data. The researcher can attempt recapture, although this option may require many additional hours of field time and may prove financially infeasible. A second option would rely on commercial or recreational fishermen to retrieve and return the tag once the fish has been taken.

The satellite tag is another type of DST tag that does not require recapturing the tagged fish to access the data. Satellite tags store data until the animal surfaces and then transmit the data to a remote receiving station. The ARGOS data collection and location system, which has receivers located on a NOAA orbiting satellite, receives and stores the transmitted data. The system uses UHF radio frequencies and its Doppler location system depends on a stable transmitter frequency of 401.640 MHz. For this monitoring technique to be successful, the species studied must surface with enough regularity to transmit data to the satellite, which is overhead for a limited number of times daily (up to 15 times at higher latitudes). While this type of tagging operation has been extensively used to track migratory patterns of sea turtles (Keinath et al. 1989), applications in fisheries research have been limited to large sharks.

The primary disadvantage of satellite telemetry is that it requires a large initial investment. Individual satellite tags can range in price from $3,000 to $4,500. This amount per single tag is approximately 10 to 15 times the amount of a single acoustic or radio transmitter. However, satellite telemetry may be cost-effective in certain situations. Mech and Barber (2002), Gorman et al. (1992), and Fancy et al. (1989) compared costs of conventional VHF and satellite telemetry and found VHF telemetry to be 43 times greater, especially when working with remote species that are difficult to track or in distant oceans. In addition, costs associated with active tracking such as personnel salaries and travel/living expenses are avoided. A principal advantage is the ability to collect several month's to year's worth of data for a single animal. Satellite telemetry tags allow collection of data that define migratory patterns, vertical movement patterns within the water column, and water temperature relationships.

**Transmitting Tags.** This category can be sub-divided based on whether the signal transmission is either "pulsed" or "coded." For pulsed tags, a simple pulsed signal, a familiar "beep-beep-beep" is transmitted at a selected pulse rate. Pulsed systems identify tagged fish through frequency separation combined with a variety of pulse rates. In theory, large numbers of fish can be tracked simultaneously by using multiple frequencies combined with different pulse rates. A limiting factor for pulsed tag usage reported in Thorsteinsson (2002) is that many researchers have difficultly distinguishing more than five pulse rates on a single frequency.

Coded tags operate by emitting a distinct and unique numerical code that differentiates it from all other tags. Coded tags offer a clear advantage over pulsed tags in that many individual fish (some manufacturers report monitoring as many as 212 on a single frequency) can be tracked separately on a single frequency. Those data can be automatically recorded by a datalogger and downloaded to a laptop computer. Radio, acoustic (sonic), and combined radio/sonic tags comprise this category. Examples of radio (upper four) and sonic (lower three) tags and their typical size ranges, manufactured by Lotek Wireless Inc., are found in Figure 1.

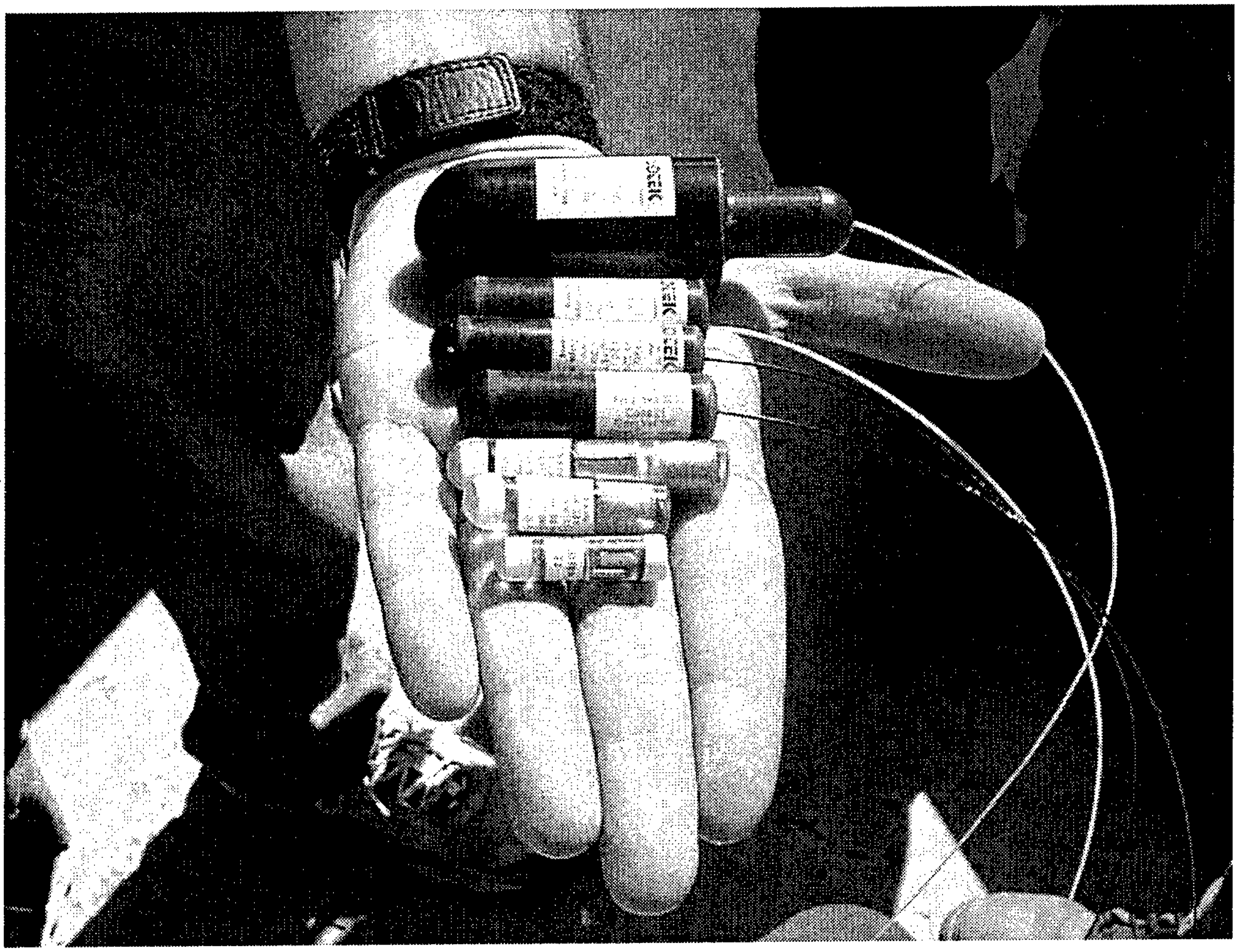

Figure 1. Radio (upper four) and sonic (lower three) tags and their typical size ranges (manufactured by Lotek)

**Radio Telemetry and Transmitters.** Radio transmitters emit radio signals from wire antennas through water and into the atmosphere. Transmissions are received with tuned antennas of varying sizes and designs. Radio tags typically operate at high frequencies (20-250 MHz) and are the preferred method in freshwater environments of low conductivity. A significant advantage of radio tags as compared to acoustic transmitters is that radio signal transmissions are less affected by physical obstacles, turbidity, turbulence, and thermal stratification (Thorsteinsson 2002). Transmission of signals by radio tags may be either pulsed or coded. Pulsed radio tags transmit a simple ratio pulse at set intervals to a radio receiver, while coded radio tags contain a programmable micro-chip, which can transmit a digitally encoded radio signal at user-defined intervals to a decoder or recorder. Radio telemetry has been successfully used to evaluate fish passage efficiency through hydropower facilities, presence and movement within riverine systems, migration patterns, response to behavioral guidance structures, habitat utilization and entrainment studies.

Habitat preferences of the target species must be considered before selecting radio telemetry as a monitoring option. If the species of interest spends a majority of time at water depths >5 m, radio

telemetry would not be the best-applied technology due to degraded signal transmission through the water column. Radio telemetry is especially effective for highly mobile fish in shallow rivers (migrating anadromous species) because aircraft surveys can often locate fish dispersed over hundreds of miles, which may be outside the normal survey range of most field crews if monitoring is conducted from a small boat.

For fishes occupying surface waters, radio tags can be detected to a distance of 1 to 3 km, when using a boat-mounted antenna. This distance is increased by several additional kilometers when antennae are mounted on aircraft. When using a land-based fixed monitoring station, site selection is extremely important since signal strength can be degraded by upland vegetation, buildings, and industrial facilities.

The operational life of radio tags has improved substantially in recent years. Two factors that most influence tag life include: battery size and the rate of signal transmission. The researcher can select optimal pulse rates based on size of the study population, duration of the study, and the mode of tracking. One manufacturer, for example, offered tags with pulse rates ranging from 30 to 240 bpm. However, increases in pulse rate mean decreases in tag life. For example, a pulsed radio tag (dia x L = 7.3 x 18 mm, weight 0.8 g) with a pulse rate of 30 bpm would last 12 days; however, if increased to 60 bpm, tag life would decrease to 7 days. Most vendors offer tags ranging in weight (in water) from 2.0 to 45 grams. Tag life varied, depending on transmission rates from as little as 7 days for the smallest tags to 3.2 years for the largest. Radio tags can be configured with delayed start times, and definable hourly, daily, or weekly activation periods, which can conserve battery life.

**Advances in Radio Tag Technology.** Continued advancement in radio transmitter technology has produced transmitters of ever-decreasing size and weight. Several companies offer a series of miniature tags. "MiniFish Tags" (AVM Instrument Company), the "NanoTag Series" (Lotek Wireless), and the "Itty-Bitty" miniature transmitters (Sonotronics) offer radio tags designed to track salmon smolt or other migratory species of similar sizes.

The standard AVM minifish tag consists of an SM1 radio transmitter, battery, tuned loop antennae, and magnetically controlled on/off switch. The overall design is roughly padlock shaped, with the loop of the antennas analogous to the shank of a padlock. Tags come in five models with an operational life ranging from 4 to 90 days. Weight in water averages less than 3 grams for the largest tag. Dimensions are generally 8 mm in thickness, 9 mm total width, and from 17 to 29 mm in length. These tags are also available for larger fish with battery life ranging from 3 months to 2.5 years. Weights for these tags range from 5 to 26 grams.

The "Itty-Bitty" miniature transmitter series manufactured by Sonotronics offers three tag models ranging in weight in water from 1.5 to 3.2 g. Length and diameter range from 25 to 36 mm, and 8 to 13 mm, respectively. Expected tag life ranges from 21 days to 5 months. Detection range is reported to be 500m+. Average costs were $250 per transmitter.

The NanoTag Series produced by Lotek Wireless is the smallest digitally encoded transmitter currently available. Using micro-circuitry design, the tags incorporate three distinct technologies; radio, digital processing, and infrared on an Application Specific Integrated Circuit. This yields a

highly stable radio transmitter with a long operational life relative to its size. Weight in air (other measurements given were in water, which is considerably less than the weight in air) is less than 3 grams for all models except the largest (4.5 g). Typical operational life ranges from 3 to 314 days. The smallest tag is 14.5 (L) x 6.3 mm (W) x 4.5 mm (H), whereas the largest tag is 309 mm in length and 9.1 mm in diameter. One model (NTC-6 Nanotag radio transmitter, size 9 mm x 29 mm) with an operational life of 299 days at a 5-second burst rate costs slightly less than $250 each.

**Acoustic Telemetry and Transmitters.** Acoustic (ultrasonic) telemetry is the preferred technology where radio telemetry is not practical, such as in deep or highly conductive (saline) environments. Ultrasonic transmitters work well in brackish or marine environments because sound is transmitted over long distances in salt water, whereas radio waves undergo rapid attenuation. Frequencies for acoustic tags range from 30 to 300 kHz. Acoustic signals can be detected manually with a small field crew, boat, and hydrophone or the process can be automated using a fixed hydrophone connected to a datalogging system. Fixed hydrophones can be either hard-wired directly to the receiver datalogger or they can be wireless, transmitting data via the hydrophone to a shore-based Yagi receiving antenna connected to the datalogger.

There is a general relationship between transmitter weight (grams), operational life of the tag (days or months), and minimum acceptable fish size (kilograms). These factors combined will determine the effective signal detection range. Depending on environmental conditions, the detection range can vary but is typically 1 km. Since the signal can only be received in water, surveys involving aircraft-mounted antennas are not possible. Acoustic signals can be degraded by a number of factors including: thermoclines, vegetation, engine noise produced by passing boats, and high levels of suspended sediment.

Similar to radio tags, signal transmission can be either pulsed or coded. Several species of fish, tagged with acoustic pulsed transmitters, have been tracked in the open sea using a directional hydrophone, portable receiver and headphones (Holland et al. 1985). This technique is suitable when knowledge of the absolute position of the target is unnecessary. If an accurate position of the target is needed, this can be achieved by triangulation using multiple hydrophones, although this will require a greater upfront expense for additional equipment. Coded acoustic tags transmit unique numerical codes that differentiate individual tags from one another. One manufacturer (Lotek Wireless) allows for tracking up to 212 unique codes on a single frequency, while retaining the ability to identify individual fish targets. This capability has two advantages over conventional pulsed systems: fewer frequencies are needed to track large numbers of fish and total scan time is reduced, as fewer frequencies are used. These advantages greatly enhance both spatial and temporal resolution of collected data.

Most manufacturers offer as many as 12 models of coded acoustic transmitters of various sizes. Cost ($200-300) per transmitter varies by manufacturer, operational life, and additional options such as depth or temperature sensors. Dimensions range from 32 to 101 mm in length, with a diameter between 8.5 and 32 mm. In water, the smallest tags weigh as little as 2 grams, while the largest tags weigh nearly 38 grams. A maximum detection range of 1000 m is reported for acoustic transmitters by all manufacturers, with the exception of miniature tags (500 m+). Environmental conditions can affect overall maximum detection range. Repeated testing, as part

of an initial pilot study, using wireless hydrophone monitoring coded acoustic transmitters (Lotek, CAFT Series) in the James River, Virginia indicated a maximum detection range of 750 m. It should be noted that windy conditions produced choppy surface conditions on the river, likely contributing to increased levels of background noise. It is recommended that study sites be evaluated for ambient noise to determine the maximum detection range for that particular system to ensure adequate coverage when deploying wireless hydrophones.

**Combined Acoustic and Radio Transmitters.** Combined acoustic and radio transmitters (CART) are hybrid tags incorporating the best features of both radio and acoustic tags. Combination tags are particularly useful in tracking the migration of anadromous fish species as they move from marine to freshwater environments. These tags, manufactured by several companies (e.g., Lotek Wireless, Sonotronics) are outfitted with a conductivity sensor to detect the salinity of the water body around the fish and a microprocessor that can automatically switch between acoustic and radio transmission modes. Both manual and automated tracking of CART tags is possible. Currently over 100 individuals can be tracked on a single frequency. Weight in water ranges from 12 to 37.7 grams for those models reviewed. Typical dimensions of CART tags range from 60 to 105 mm in length and 16 to 18 mm in diameter. Tag life ranges from 1 year for the smaller tags (13.5 g) to greater than 5 years for the largest (37.7 g) transmitters. Acoustic frequencies range from 32 to 83 kHz, although most companies will typically manufacture tags at one or two selected frequencies (e.g., Lotek, 65.5 and 76.8 kHz). Some manufacturers require separate receivers to detect individual radio and sonic transmissions. Cost per single combined acoustic radio transmitter can be as high as $450.

**Sensors Used in Ultrasonic Transmitters.** Acoustic transmitters can be equipped with a variety of sensors, such as pressure (depth), temperature, velocity, heart rate, and accelerometers. The data from these sensors are usually encoded in the repetition rate of the transmitted pulses. Some transmitters can be outfitted with more than one sensor. Velocity sensors are used to measure animal swimming speeds or water flow rates. Heart rate sensors can be used to measure electrical signals generated during muscle contractions and therefore can be used to monitor heart rate if the transmitter is placed near the tagged animal's heart. Accelerometers gather fine-scale three-axis measurements of acceleration. Applications include measurement of tail beat frequency and amplitude and mortality.

## ANTENNAS, HYDROPHONES AND RECEIVER/DATALOGGERS

**Antennas.** The selection of receiving antennas is often not given adequate attention. Proper antenna selection can mean the difference between receiving the necessary data and receiving no signal at all. Selection of the appropriate antenna is important because only half of the transmitter signal captured by the antenna is delivered to the receiver while the other half is re-radiated. Matching the right antenna to its application can result in increased signal reception by as much as threefold. Antennas can be divided into lightweight hand-held models and larger models that may be fixed either on shore-based monitoring stations or survey vessels. Types of hand-held antennas used in telemetry tracking include the three-element Yagi and the loop antenna. Loop antennas can be circle, oval, or diamond shaped. Hand-held antennas, such as the "Handi-Loop" (available from AVM Instruments) measure only 6 x 10 cm. They provide excellent short-range gain and directional accuracy in places where bulky Yagi antennas are impractical.

Widely used fixed and mobile antennas include the 4-, 7-, and 12-multi-element General Purpose Yagi. The Yagi antenna is the standard directional receiving antenna and is the most commonly used antenna in radio telemetry. The basic model consists of a boom, generally about 1 meter in length, with three elements of equal length. The length of the elements, as well as the spacing between them, is the inverse function of the frequency for which the antenna was designed. The three elements are referred to as the reflector, driven, and director. The addition of each subsequent director element increases the overall range of signal detection. The signal is passed through a coaxial cable equipped with a BNC connector, from the driven element to the receiver/datalogger.

**Hydrophones.** A hydrophone is an electronic receiver for detecting or monitoring sound traveling through water by converting acoustic energy (sound energy) into electromagnetic waves (electrical energy) by use of a ceramic transducer. High quality hydrophones contain internal low noise pre-amplifiers to increase the amplitude of signals at their source and to reduce noise as the signal is transmitted along the cable. Potential sources of noise include the power supply and electrical interference, although in well-designed units this is usually not a significant problem. An external source of noise can result from water flow if the hydrophone is attached to a moving vessel. Assuming that the hydrophone is mounted in an area in which water flow is smooth, this noise is dominant when compared to noise generated by the vessel itself. For a typical hydrophone, the effect of flow noise will be insignificant up to a vessel speed of a few knots. Beyond this point noise will increase dramatically (~18 db for every doubling of vessel speed).

There are different types of hydrophones to match different receivers, users and applications. Hydrophones may be either directional or omni-directional. Omni-directional hydrophones receive signals from all directions with equal sensitivity. They are typically used for data telemetry from captive animals or stationary transmitters. Some models, such as the Sonotronics DH-3, are typically used in small pools with a detection radius of tens of meters. Directional hydrophones have a greater sensitivity to signals from a particular direction, and are used in tracking to determine the direction of the transmitter. Directional hydrophones can use either a single transducer element with a dish or conical-shaped sound reflector to focus signals or a more complex array system, which uses transducers of one or more elements in an array. For frequencies used in tracking, a "line array" provides a manageable size hydrophone. Note that the beam width of a "line array" hydrophone is a function of the signal frequency and is therefore only suitable for a range of frequencies. For example, the VH10 hydrophone, manufactured by VEMCO, is designed for use between 50 and 80 kHz and can only be used for transmitters within this frequency range (VEMCO Models V8 and V16 transmitters). Transmitters with lower frequencies, such as their V22 and V32 line, would require a hydrophone designed for that specific frequency range.

Hard-wired hydrophones can be used where the study site permits. Bottom mounting of hard-wired hydrophones tends to provide better position accuracy. Hard-wired systems are also less expensive when compared to radio-linked systems. A comparison of one model of wired-hydrophone (LHP-1) manufactured by Lotek Wireless averaged under $700, or approximately six times less expensive than the wireless models ($4500). The most frequently cited

disadvantage of using a hard-wired monitoring system is the limitation on cable length due to noise propagation, which typically limits deployment to within 100 m from shore. Advancements in wired hydrophones (Lotek Wireless Model LHP-1) enable cable runs of up to 1000 m by incorporating an amplifier that generates a differential signal drive. The LHP-1 can be configured for either omni-directional or directional operation with a bandwidth of 20 to 80 kHz, and can be used for both datalogging and manual tracking applications. Most manufacturers market a number of models of "wired" hydrophones since it is necessary to match tag frequency and receiver type.

Wireless hydrophones are a hybrid technology that incorporates the flexibility of radio telemetry in acoustic applications, while eliminating the inherent limitations created by lengthy cables between the transducer and the receiver. Wireless hydrophones are capable of detecting underwater acoustic signals and relaying those signals through the air by way of a VHF transmission to a radio telemetry receiver located on a shore-based monitoring or recording station. Wireless hydrophones are typically tethered to a buoy and anchored at the monitoring site. This deployment method significantly reduces deployment time over conventional acoustic hydrophone or bottom-moored datalogging systems. A typical deployment scenario would include one or more wireless hydrophone deployed across the cross-channel profile of a river creating a monitoring gate through which all tagged fish migrating upstream would have to pass. Data from each of the wireless hydrophones could be transmitted to a single shore-based datalogging receiver. This automated tracking feature allows for real-time, around-the-clock monitoring with minimum personnel requirements.

Wireless hydrophone models are typically less than 20 in. in length and can be deployed to depths of 100 m. They are deployed using "D-cell" batteries as a power source, which last from 4 to 6 months and are easily changed in the field. Both single- and dual-acoustic channel retransmission via VHF models are available. Single-acoustic models are typically used for studies that examine movement patterns of large numbers of solitary animals, while dual-acoustic models are suited for applications involving larger numbers of tagged animals, which may congregate in the same study area.

**Receiver/Dataloggers.** Most manufacturers of telemetry equipment offer several models of receiver/dataloggers that enable the researcher to conduct automated tracking studies, carry out real-time field tracking, or collect detailed positioning data. Receivers can be fixed to boats or aircraft for manual tracking, or land-based monitoring stations for automated tracking studies. Manual tracking is often used in studies of gross fish movement, migratory patterns and the location of spawning grounds. In the past, manual tracking involved a manual search for signals on every assigned frequency. This labor-intensive process has been eliminated with the development of scanning receivers that automatically listen for a small period of time at each assigned frequency. When a signal is detected, the scanning cycle can be suspended to locate the animal. Scanning receivers can be classified by their intended usage as either "general-purpose" or "specific application." Two examples manufactured by VEMCO include the VR60; a general-purpose ultrasonic receiver designed for manual tracking of aquatic fish species, typically from small boats, and the VR25, which is used in fish and small animal tracking specifically around hydroelectric utilities. Note that some receivers are designed for either manual or automatic tracking, but don't have the capability to do both functions in a single unit. Examples of manual

tracking receivers include the USR-5W and USR-96 manufactured by Sonotronics. These models measure pulse intervals, a function of depth and temperature, as a means of identifying non-coded tags. The USR-96 is a narrow band receiver, which improves the detection range and distinction between tags and is ideal in areas of high background noise. Conversely, their model USR-90 is a dedicated automatic tracking system, which is suitable for fixed stations, but cannot be used for manual tracking.

Lotek Wireless first introduced fixed-station datalogging systems in the 1980's. In this application, one or more receivers are deployed to automatically scan for frequencies in use. Advances in technology have produced scanning receivers capable of both manual tracking and automated datalogging combined into a single unit (e.g., SRX-400 manufactured by Lotek Wireless). During automated tracking, when a valid transmitter is detected, the system records the time, date, frequency, pulse rate, individual code number (if using coded tags) and signal strength of the detected fish. A major advantage of scanning/datalogging receivers is continuous data collection throughout the study period. This technique allows for more data to be collected than is possible from manual tracking when considering the amount of manpower needed and associated costs. After initial setup, a single researcher can periodically visit each shore-based fixed-station monitoring site to download stored data. Depending on the number of tagged fish being monitored, this may be as seldom as once a week. Data are transferred via an RS-232 serial port to a standard laptop computer. A standard marine battery powers the shore-based system.

Features to consider when investing in scanning receivers include: the ability to simultaneously monitor multiple frequencies; acoustic and radio frequency monitoring using the same receiver; number of individual fishes that can be monitored on a single frequency; detection of coded and non-coded transmitters; both manual and automated tracking capabilities; the ability to function within a remote environment in self-contained operation and remote access capability via cellular phone, radio modem, or satellite.

**HIGH RESOLUTION TRACKING:** Several telemetry equipment manufacturers produce systems that are capable of providing real-time, detailed position information of acoustically tagged fish. Steig (1999) investigated the use of acoustic tags for monitoring juvenile salmon and steelhead as they migrated downstream in the forebay of the Rocky Reach Dam on the Columbia River. The tracking system utilized four fixed, wide beam hydrophones with overlapping beams. Each hydrophone was placed at a known location within a three-dimensional grid. Acoustically tagged fish passing through the four beams were detected and mapped to sub-meter accuracy by using the arrival time of each pulse to triangulate the position of each fish. The fish's three-dimensional movement trajectory was tracked over time. Hydroacoustic Technology Incorporated (HTI) states that 20 fish could be tracked through the facility simultaneously.

VEMCO's Radio Acoustic and Positioning System (VRAP) employs a similar concept to the HTI system and is used to measure real-time, high-resolution position information by deploying a series of detection stations attached to buoys. Buoys are easily deployed from a small boat and have side and bottom mooring lugs. Each buoy contains a hydrophone, ultrasonic receiver, two-way radio link, a microprocessor controller, and a rechargeable battery as a power source. Following initialization, a detected transmitter is positioned based on arrival time of the acoustic

ping to each buoy. Depending on environmental conditions, position accuracy is to within 1 or 2 meters. VRAP software gives the user the ability to process the true latitude and longitude position of each tag. If standard acoustic pingers are used for tracking, VRAP software will calculate the x and y position of the transmitter. If three-dimensional (3D) data are required, the z (depth) coordinate can be determined in one or two ways: use of a depth transmitter, or manual entering of the depth information if the animal is at a relatively constant water depth.

Lotek Wireless also employs a version of the MAP system to detect acoustically tagged fishes in high noise environments. The MAP-600 is a multi-port receiver of tethered hydrophones. Hydrophones are hard-wired to the receiver by a 600-m cable. Each receiver can support up to eight paired hydrophones. Typically six or more hydrophones are deployed for 3D positioning at sub-meter precision. This system has a tag identification capacity of tens of thousands on a single frequency, and the ability to simultaneously track hundreds of transmitters with high broadcast rates. Real-time data can be recorded directly to a PC or stored on an industrial Type 1 solid-state flash card.

All three systems are capable of giving real-time positioning data in high noise environments. High-resolution tracking systems should be considered when data requirements dictate precise movements of fishes around dams, hydroelectric facilities, and reservoirs. Costs are relatively high, setting a limit on feasible spatial coverage.

**FISH HANDLING:** A fundamental aspect of tagging is survival of the fish during and after the tagging process. Fish species vary greatly in their ability to be handled. While some species can endure a considerable degree of handling stress, others such as the American shad (*Alosa sapidissima*) can show stress response and potential mortality correlated with handling effects. Many factors must be given adequate consideration when assessing potential handling effects on a given species. One of the most important is the method of capture (netting, trawling, electro-fishing). Trawls may cause considerable injury to fish stemming from rocks and other debris that may be collected during the trawl as well as injury resulting from the spines of other fish. Whenever trawling is employed as a method of capture for tagging studies, towing times should be minimized. Netting (e.g., gill netting, seining, pound netting, fyke netting) will typically be less invasive than trawling, but success will depend on the type of netting deployed and time intervals between "fishing" the nets. An example of potential effects of netting on tag fish can be seen in a pilot study involving upstream preproductive migration of American shad. In this study, fewer detections were made at spawning grounds in the James River, Virginia of tagged American shad for individuals captured by gill nets when compared to haul seines (Olney et al. 2004). Gill netting therefore must be considered a relatively stressful option unless "gilled" fish are promptly removed. Various types of fish traps and bag nets may be preferable ways of catching fish for tagging, but are not always possible. Electro-fishing has been used to catch fish for telemetry studies. Although long-term effects may be minimal if used properly, injury and mortality can result if the voltage and type of electrodes used are not properly considered. Fish species and size, and environmental conditions such as conductivity (electro-fishing not feasible in saline waters), depth, temperature and substrate are also determinants of the viability of electro-fishing.

Properly transferring fish from the net or trawl to the tagging station is also important in reducing stress. If fish are to be transported from the catch site to a tagging location, water-filled plastic bags or suitable containers will minimize injury to the fish. Whenever possible exposure of the fish to air should be avoided. Two studies indicated that the use of in-water transfers reduced 96-hour mortality from 82 percent to 15 percent in American shad (Murai et al. 1979) and reduced long-term mortality from 52 percent to 15 percent in Atlantic salmon (Flagg and Harrell 1990). During tagging, the use of tagging cradles, troughs, or holders to keep fish immobilized is recommended. If anesthesia is used, type and exposure dosage will vary between species, as well as recovery times. In many situations newly tagged fish should be monitored in a holding tank until there is evidence of full recovery (e.g., resumption of normal swimming behavior and respiration). When fish are kept in a holding tank, water quality, temperature, and duration held must be monitored.

**TAG ATTACHMENT METHODS:** The method of tag attachment (external or internal) is another consideration when planning a telemetry study. External attachment typically involves the use of barb darts, pins or sutures, whereas internal tagging requires the insertion of the tag through the esophagus into the stomach, or the surgical implantation in muscle or the abdominal cavity. Both attachment methods have advantages and disadvantages, which depend on the type of transmitter selected, the species and behavioral characteristics of the fish species to be studied, and the type of data required from the research.

**External Tagging.** External attachment typically involves suturing the tag directly to the body of the fish, or using fine wires or nylon cords, which pass through the body musculature, and are anchored by plastic discs or plates on the opposing side of the fish. The most common position for external attachment is along the base of the dorsal fin as described by Gray and Haynes (1979), who used this method to attach radio tags to salmonids. Other methods of external tagging include single-point attachments, which have been widely used with sharks and tethered tags that require a strong permanent anchor point. For fish species that are not easily captured, tethered tags typically consist of a dart with an arrowhead that resists extraction from muscle tissues. Detailed descriptions and variations to external tagging procedures are described in Thorsteinsson (2002). For some species, like flatfishes (e.g., plaice, *Pleuronectes platessa*) external tagging may be the only option due to a tightly coiled gut and small peritoneum, eliminating internal tagging as an option. External tagging may also be necessary with species that may be difficult to bring onboard, such as sharks, and large pelagic fish (e.g., tuna, marlin).

There are both advantages and disadvantages to external tagging. Most notably external tagging is usually simpler and can be performed much faster than internal tagging methods. In addition, it can be done without surgery or anesthesia. The primary disadvantage with external tagging may be adverse effects on behavior and physiology of swimming animals caused by hydrodynamic drag. Chafing, abrasion, and ulcerated wounds may also be problematic, primarily with tags that have extended battery life, most notably archival tags.

**Internal Tagging.** Internal tagging can be accomplished through insertion of a radio or acoustic tag into the stomach, oviduct, or through intra-peritoneal surgery. Stomach insertion may be voluntary or forced ingestion. In voluntary ingestion, acoustic transmitters are embedded in bait and ingested by the species of interest. This is usually confirmed by viewing the bait with

an underwater 35-mm camera. In forced ingestion, the tag is pushed into the stomach with a glass or plastic rod. The tag is usually lubricated with glycerine or other suitable product. Tagged fish are generally marked so commercial and sport fishermen can return tags (usually only necessary if an archival tag is used). If radio transmitters are used the tag wire is typically fed back through the gill slits and allowed to trail freely in the water. Forced insertion of acoustic tags was used on 29 pre-spawning adult American shad as part of a pilot study on the York River, Virginia (Olney et al. 2004). All but two tagged fish were successfully detected at upriver spawning grounds.

A chief concern with stomach-inserted or ingested transmitters is loss of a tag through regurgitation or egestion. Regurgitation rates vary greatly, depending on the fish species and the relative size of the tag (Nielsen 1992). Table 1, adapted from Nielsen (1992) lists species with high and low potential for retaining gastrically inserted radio and acoustic transmitters.

**Table 1**
**Fish Species with High and Low Potential for Retaining Gastrically Inserted Transmitters as Adapted from Nielsen (1992)**

| **Species Likely to RegurgitateTag** | | **Species Unlikely to Regurgitate Tag** | |
|---|---|---|---|
| American shad | *Alosa sapidissima* | White sucker | *Catostomus commersonni* |
| American eel | *Anguilla rostrata* | Northern pike | *Esox lucius* |
| Brown bullhead | *Ictalurus nebulsus* | Atlantic cod | *Gadus morhua* |
| White bass | *Morone chrysops* | Skipjack tuna | *Katsuwonus pelamis* |
| Striped bass | *Morone saxatilis* | Coho salmon | *Oncorhynchus kisutch* |
| Pink salmon | *Oncorhynchus gorbuscha* | Rainbow trout | *Oncorhynchus mykiss* |
| Chum salmon | *Oncorhynchus keta* | Yellow perch | *Perca flavescens* |
| Sockeye salmon | *Oncorhynchus nerka* | Atlantic salmon | *Salmo salar* |
| Chinook salmon | *Oncorhynchus tshawytscha* | Brown trout | *Salmo trutta* |
| Bluefin tuna | *Thunnus thynuus* | Sauger | *Stizostedion canadense* |

Oviduct insertion has been used successfully with salmonids. Transmitter wires were allowed to freely trail from the oviduct. Some studies reported expulsion of the tag within 7 to 13 days, although Peake et al. (1997) reported retention longer than 14 days and up to 60 days for 70 percent of tagged fish. They also reported that this technique might be suitable for sturgeon (Acipenseridae) as well as several other taxa.

Another common method of internal tagging is intra-peritoneal surgery, which has been used successfully for the past 20 years with several species of marine and freshwater fishes. In this technique, a small incision is made in the body wall of the fish with a sharp scalpel. Mid-ventral incisions are more commonly used than lateral incisions, reducing the chance of damage to the internal organs, while decreasing the time necessary for healing of the wound. Incision length should be as short as possible, but is determined by tag length and diameter. Shorter incisions typically have less risk of tag expulsion and shorter healing times. Incisions are typically closed with sutures or surgical staples. Surgical stapling is a quicker method of incision closure, but requires removal of more rows of scales, which could lead to greater risk of infection. This method of tagging requires adequate training of personnel to reduce injury and mortality to tagged individuals.

**CAPITAL INVESTMENT:** Research goals can best be achieved only after careful consideration is given to study design. However, the initial investment in equipment is frequently cited as a limiting factor when designing a study. Manual tracking may have the least capital cost when compared to a fully automated tracking system; however, when factoring in the cost of manpower for manual tracking, fully automated systems may actually be the better value. The duration of the study is often a key factor in the optimal type of system deployed.

The minimal equipment necessary for manual tracking would be tags, a hydrophone, and a receiver. Scanning receivers averaged $2000 to $3000 for those models reviewed. Omni-directional and directional hydrophones typically average $350 and $600 per unit, respectively. Major expenses are incurred in the purchase of radio and acoustic transmitters, whose cost ranged from $150 to $300 each. Some manufacturers have combined radio and sonic transmitters for as much as $450 per unit. These transmitters are typically not recovered and are considered expendable.

For fully automated systems, scanning receivers with datalogging functions and the capability of monitoring both acoustic and radio frequencies typically costs $8,000 each. Wireless hydrophones average from $4,500 to $5,000 per unit. Wired hydrophones generally cost less (<$750) but will typically require more deployment time, especially if bottom–moored. The decreased cost of field personnel may offset the higher costs associated with the initial purchase of wireless hydrophones. Transmitter prices varied based on operational life and other features. One example is a coded acoustic transmitter (76.8 kHz) with an operational life of 92 days at a 5-second burst rate that costs $275 per transmitter. Therefore based on tagging 100 fishes during an andromous fish migration study, at $300 per tag, the transmitter investment alone would be $30,000. Depending on the system (wired vs. wireless monitoring) costs associated with additional hardware requirements can be substantial including wireless hydrophone antennas ($400 per unit); remote terminal control options ($921 each); ultrasonic up-converters ($902 each); directional baffles ($55 each); mounting brackets ($220 each); float assembly ($110 each); marine batteries to power shore-based stations; and anchors, chain, stainless steel cable, and other expendables.

**CONCLUSION:** As discussed above, there are obvious financial, design and logistical considerations in telemetry research. A variety of instruments and techniques are available for monitoring freshwater and marine fishes. Selecting the proper equipment and establishing clear and concise research objectives are critical to the success of any monitoring effort. Consideration must be given to the species to be studied, its environment, and the type of data needed to meet research goals. This in turn will factor prominently in the type and size of transmitter selected and subsequently in the type of receivers and hydrophones necessary, as well as the appropriate deployment strategy. Flexibility of the system along with a capability to upgrade components to accommodate multiple projects over a span of years should also be considered.

**TELEMETRY EQUIPMENT SUPPLIERS:** As an aid to the reader, web site addresses of telemetry gear manufacturers mentioned in this technical note are given below. Although the list is not exhaustive, it does reflect some of the leading companies in telemetry equipment manufacturing including Advanced Telemetry Systems (www.atstrack.com); AVM Instrument

Company (www.avminstrument.com); Biomark Inc. (www.biomark.com); Destron Technologies (www.destronfearing.com); Hydroacoustic Technology Inc. (www.htisonar.com); Lotek Wireless Inc. (www.lotek.com); Sonotronics (www.sonotronics.com); Trovan Limited (www.travan.com); and VEMCO (www.vemco.com). The inclusion of any company name or its products and services does not imply endorsement by the United States Government.

**POINTS OF CONTACT:** For additional information, contact the author, Mr. Kevin. J. Reine (601-634-3436, Kevin.J.Reine@erdc.usace.army.mil), Wetlands and Coastal Ecology Branch, Ecosystem Evaluation and Engineering Division, Environmental Laboratory; Dr. Douglas G. Clarke (601-634-3770, Douglas.G.Clarke@erdc.usace.army.mil), Focus Area Manager; or Dr. Robert M. Engler (601-634-3624, Robert.M.Engler@erdc.usace.army.mil), Program Manager of the Dredging Operations and Environmental Research Program. This technical note should be cited as follows:

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